# The Study of the Optimal Route for Waste Collection by Using Vehicle Routing Problem in Chulachomklao Royal Military Academy

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**Abstract :** The waste problem in Chulachomklao Royal Military Academy has been increasing and affecting the environment, including the quality of personnel's lives. Waste disposal has become increasingly challenging due to changing consumption patterns, necessitating more energy. Presently, the Transportation Section of the Support Division in Chulachomklao Royal Military Academy is responsible for collecting solid waste from government offices and residences for disposal at the landfills managed by the Prommanee Sub-district Administration Organization in Nakhon Nayok Province. However, the support for waste trucks is insufficient in terms of equipment availability due to the limited number of waste trucks. Therefore, proper management of waste collection, particularly in terms of transportation planning is crucial. This research aims to solve these issues by applying a mathematical model for the Vehicle Routing Problem (VRP) and Heuristic Principles including the Cluster-First Route-Second method and the Sweep Heuristic method to find the most optimal waste collection route. Furthermore, a comparison with traditional transportation methods is conducted to identify the shortest route and provide guidelines for resource-efficient waste collection planning. The study concludes that the Cluster First Route Second+ VRP 2 Group method exhibits the shortest transportation distance, reducing the original 110.71 kilometers route to a total of 75.66 kilometers. This reduction in distance also leads to a decrease in transportation costs by 1,525.09 baht per week, equivalent to 31.66 percent of the original transportation costs.

**Keywords:** Optimal Route, Waste Collection, Vehicle Routing Problem, Mathematical Model, Heuristic Principles

## 1. Introduction

Presently, the situation of waste management and hazardous waste has been an environmental problem in Thai society for a long time due to the amount of solid waste has increased according to the population rate, economic growth and public consumption. Although there is management according to the National Solid Waste Management Master Plan (2016–2021) [1], it is still insufficient to handle the amount of solid waste that tends to increase every year.

In 2020, there was approximately 25.37 million tons of solid waste. When considering the overall situation of municipal solid waste management, it was found that 8.36 million tons of solid waste were sortedand reused. Related factors include: Many municipalities don't allow people to sort waste at municipal solid waste disposal sites due to fears of the spread of infection from rubbish dumping that maycontain pathogens. The global economic crisis caused by the impact of the Coronavirus disease in 2019 has caused many antique shops to close down. As a result, the amount of municipal solid waste that was reused decreased, dividing into about 7.88 million tons of municipal solid waste that were improperly disposed and 9.13 million tons of municipal solid waste that were properly disposed [2].

The amount of hazardous waste generated by communities in Thailand in 2021 was 669,518 tons, most of which were scrap electrical and electronic products 435,187 tons or 65%. Hazardous waste from other communities such as batteries, chemical containers and cans total 234,331 tons or 35%. Comparing the amount of hazardous waste from the community in the past year, it was found that the amount increased due to the local government organizations and the private sector setting up waste collection points in community areas and department stores for people to conveniently dump waste. An overview of the generation of hazardous waste in the community during the years 2014-2021 found that the amount of waste generation tends to increase continuously every year and has an average constant of 1.60% since 2019. As a result of the epidemic situation of the Coronavirus disease 2019, the consumption behavior of people in the country has changed with increasing demand for electrical appliances and electronic devices, more frequent replacement of equipment to keep up with modern technology, imported low-quality products that shorten product life and cause hazardous waste [3].

The situation with solid waste within the Royal Thai Army is facing the same problem as the rest of the country due to rising consumption and rapidly changing technology. An example of the problem of municipal waste management by local administrative organizations that affects the Army is the waste collection pond of the municipality of Nakhon Si Thammarat Province. There is a problem of overflowing waste that affects the health and environment of the community with polluted water draining into agricultural areas and water sources, causing sickness among the villagers in the area. Waste ponds have residues in plants, local foods and aquatic animals used as food by villagers in the area, which directly affect the waste management of the 41st Military Circle [4].

The waste problem in Chulachomklao Royal Military Academy or CRMA has been continuously increasing. From the collected data, the average amount of solid waste is 6 tons per day. Disposing of solid waste is becoming increasingly difficult and energy-consuming but the support of garbage trucks is lacking due to the delivery rate. The number of garbage trucks is limited, so waste collection must be properly managed in terms of transportation planning, which is to bring solid waste collected from government offices and residences to the waste disposal site according to the amount of waste. The distance between waste collection points and the number of rounds of transportation affect waste collection within the CRMA as shown in Figure 1.

Based on this concept, the researcher studied the optimal route for waste collection using the Vehicle Routing Problem or VRP principle to propose a waste collection method that uses the resources of transportation equipment cost-effectively, reduces waste collection distance and is beneficial to the government for the next action plan.

## 2. Objectives

2.1 To study the waste collection route of the Chulachomklao Royal Military Academy.

2.2 To design the optimal route for waste collection in Chulachomklao Royal Military Academy.


**Figure 1** A bird's-eye view of CRMA from Google Maps

## 3. Literature Review

### 3.1 Reduction and segregation of solid waste

The Pollution Control Department [5] explain that "solid waste" means unused items, paper scraps, fabric scraps, food scraps, product scraps, plastic bags, food containers, ash, manure, carcasses, anything else that is cleared from a street, market, animal feed, products left over from homes, shops, markets, establishments, workplaces, or any other place, etc. Therefore, in order to make the management of solid waste easier to implement, there should be a good plan and the types of solid waste can be divided into four categories as follows:

3.1.1 Recyclable waste: this type of waste will be no problem of contaminating organic waste. it will not smell and it will be easy to recycle by selling it to antique shops and entering the recycling industry to be processed into raw materials or new products such as glass, paper, plastic, metal and etc.

3.1.2 Compostable waste: this type of waste can be collected and used to make compost and biofertilizer. If combined with other types of waste, it will cause rottenness and it is essential that it be sorted out and handled properly such as vegetable scraps, fruit scraps, food scraps and etc.

3.1.3 Hazardous waste: this type of waste, when combined with general waste, will contaminate the soil, water, air and cause adverse effects on living organisms and the ecosystem. It must be properly disposed such as light bulbs, batteries and etc.

3.1.4 General waste: this type of waste is harmless and not worth recycling. After separating solid waste, responsible agencies will dispose of it further.

**3.2 Definition of vehicle routing problem**

T. Phannikul [6] defined VRP as the arrangement of routes for transporting goods from distribution centers to customers at various points to help support decision making for system users. It has a single distribution center and a loading capacity constraint model that considers the weight and volume of the cargo under the condition of vehicle capacity with the goal of achieving the shortest distance. Vehicle Routing Problem or VRP is a transport and logistics problem that focuses on delivering on-demand goods to customers with a starting point and ending at a warehouse. The goal is to provide the shortest travel route and the lowest cost. Factors related to routing include:

3.2.1 Set of customers

Each customer is assigned to a different node and needs to receive or deliver different amounts of goods and additional time requirements may be set.

3.2.2 Vehicles

Trucks, ships, planes or transport arrangements that provide services to customers traveling between customers and warehouses with load limitations may be defined as the number of pieces of cargo or the maximum weight of cargo that can be carried per vehicle.

3.2.3 Depots

All warehouses, manufacturing plants or distribution centers are locations that are defined as starting and ending points in a journey. Every vehicle must travel from this point to serve the customer to various points and return to the same point. The complex problems may require many warehouses to serve many groups of customers.

3.2.4 Routes

Assigning any vehicle to travel to different points or any customer and how to travel in an order that consists of sub-paths or multiple paths.

**3.3 Find solutions for vehicle routing problem**

P. Chunchaiphak [7] studied methods for finding answers to VRP. Finding results or solving problems has two goals. First of all, the quality of the answers can be guaranteed by providing the most optimal answer, specifying the scope of the quality of the answer, and finally by guaranteeing the timing or speed of finding the answer. The way to find the answer is as follows:

3.3.1 Optimization

VRP is a discrete decision problem or an integer programming problem because the answer is only 0 or 1, i.e., the vehicle will travel (X = 1) or not travel (X = 0). The method for determining which option is the best answer (optimal solution) is sequencing. The sequencing method involves substituting all the variables to make possible alternatives. After that, the answers are compared to choose the best answer, which is called complete enumeration. It takes a long time to find the answer to a large problem and there is almost no answer so this method is not popular.

How to find the best solution to discrete decision problems. There are many techniques for solving problems, such as the Branch and Bound method, Calculation method using the LINGO program and the CPLEX program and etc. There are also several other methods as mentioned above. The Vehicle Routing Problems (VRP) are categorized as NP-hard problems and the answers are numerous. When considering how to find the best answer (optimal solution) in a limited time, it's not suitable for solving problems. Therefore, there are ways to find an answer that provides a value close to the best answer (a near-optimal solution) using Heuristic and Metaheuristic.

3.3.2 Heuristic methods

Heuristic comes from the Greek word "Heurisko" or "Heuriskein" meaning discovery. It was invented to solve specific problems. Heuristic methods are neither arbitrary nor fixed. The answer may or may not be the best answer, but it is acceptable and involves quick calculations, such as the Saving Heuristic, Nearest Neighbor, Sweep Heuristic, Cluster-First Route-Second, and etc.

3.3.3 Metaheuristic method

This method is commonly used to solve non-polynomial problems such as production scheduling and VRP, similar to heuristic methods. Because of the broader concept of finding a solution, it can be applied to a wider range of decision-making problems than heuristic methods. The popular metaheuristic methods used to find answers such as Genetic Algorithms, Ant Colony, Tabu Search, Local Search and etc.

3.3.4 Neighborhood Solution Method

Answer improvements from default answer generation to a better answer and bring the answer closer to the best answer, such as Swap, Two-opt, Exchange Heuristic, One Move Heuristic and etc.

**3.4 Related Research**

P. Chunchaiphak [7] applied Heuristics to route school bus for students. There are a total of 1,137 pick-up and transfer students per day who need to be transferred at 39 transfer points. The first step is dividing all transfer points into groups based on their degree. Then, all four heuristic methods, including the Nearest Neighbor heuristic, Clarke-Wright Saving heuristic, Sweep Heuristic, and Farthest-Nearest Neighbor heuristic, were applied. Three types of vehicles were determined: a pick-up, a six-wheel truck, and a bus. The capacity for each vehicle was determined based on the number of seats. The results showed that using the Clarke-Wright Saving heuristic with a bus yielded the shortest distances at 733 kilometers per round and incurred a fuel cost of 206,283 baht per month. When compared with the original cost, it was reduced by 134,817 baht per month.

P. Phanphiphat and P. Khemavuk [8] studied the route of trucks to reduce the distance in Multiple Depot VRP transportation. The research determines the locations of 12 factories, ports and transported by one truck. Then it compares the traditional transportation routing with the heuristic method by using the Nearest Neighbor Method and the applied Saving Algorithm. The results of the study concluded that the Nearest Neighbor Method has the shortest transport distance. The original transportation route is 4,118 km long, with 40.79% of the proportion without cargo in the vehicle. The Nearest Neighbor Method route has a total transportation distance is 3,722.9 km with 34.50 % of the proportion without cargo in the vehicle. Moreover, the applied Saving Algorithm method (four stages) has a total transportation distance is 4,008.1 km, with 39.16 % of the proportion without cargo in the vehicle.

P. Kabcome and T. Mouktonglang [9] presented a mathematical model to solve the vehicle routing problem with soft time windows (VRPSTW) and the distribution of products with multiple categories.In addition, they include multiple compartments and trips. Each compartment is dedicated to a single type of product. Each vehicle is allowed to have more than one trip, as long as it corresponds to the maximum distance allowed in a workday. Numerical results show the effectiveness of the model.

N. Rungrodchatchaval et al. [10] applied VRP to find a new route for waste collection to have the least distance by using the Savings Algorithm and Evolutionary Method in the Microsoft Excel Solver program by considering two cases as follows: Travel one route and two routes. The results show that the evaluation method provides the path with the least distance and has a more balanced workload than the current route and the route from the Savings Algorithm method.

J. Banthao et al. [11] proposed the application of a mathematical model for VRP to design routes, reduce costs and increase the efficiency of liquor shipments. Under the following conditions for transportation to 24 stores, four trucks were used, each with a loading capacity of 70% of the trucks. The trucks were divided into two large trucks with a loading capacity of 350 crates and two small trucks with a loading capacity of 210 crates. The results of the experiment found that the new route was organized with a reduced distance of 143.41 kilometers or 19.83%, and the cost of travel decreased by 1,195.50 baht per week or 18.84%.

## 4. Research Methodology

The methodology steps as shown in Figure 2.

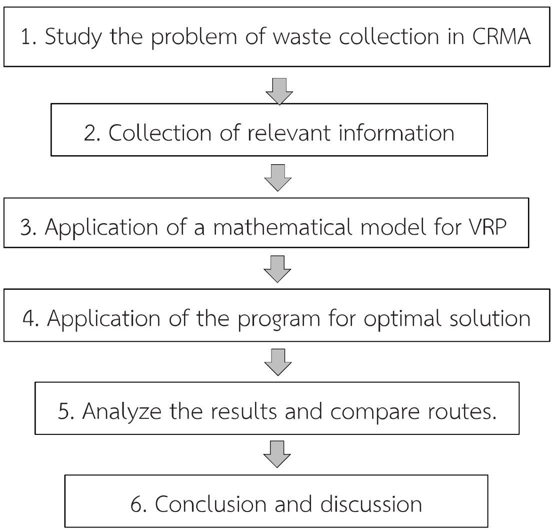


**Figure 2** Research Process

### 4.1 Study the problem of waste collection in CRMA

The transport section of the CRMA general support division operates waste trucks to collect waste on a Monday-Friday cycle. The division of waste collection points at government offices and residences totals 45 locations with the amount of waste 128.2 tons. Then disposed in landfills managed by the Prommanee Subdistrict Administration Organization of Nakhon Nayok Province, which has a total distance of 110.71 kilometers. Traditional waste collection routes create unnecessary distances. From the problems, the researcher uses the transportation limitation factor for designing the waste collection route to find the most optimal route and reduce transportation cost.

### 4.2 Collection of relevant information

4.2.1 The Depot is located at the waste truck stop of the CRMA General Support Division's Transport section, as shown in Figure 3.

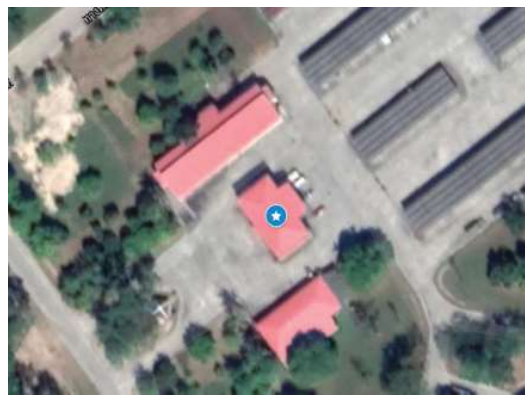

**Figure 3** Waste Truck Depot

4.2.2 Set of customers is defined as waste collection points at 45 government offices and residences as shown in Figure 4.

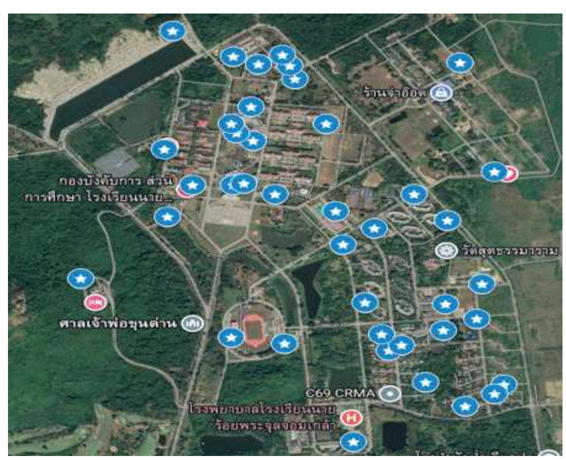


**Figure 4** Waste Collection Points

4.2.3 Coordinates of government offices and residences using geographic coordinates from Google Maps are latitude and longitude as shown in Table 1.

**Table 1** Coordinates of 45 Waste Collection Points

| Code | Waste Collection Points | Latitude | Longitude |
|---|---|---|---|
| A1 | CRMA Transportation Section Headquarters | 14.3060 | 101.1665 |
| A2 | CRMA General Support Division Headquarters | 14.3056 | 101.1675 |
| ... | ... | ... | ... |
| A44 | CRMA Club | 14.2788 | 101.1633 |
| A45 | Landfills Prommanee Sub-district Organization | 14.2118 | 101.1435 |

4.2.4 Determine the distance of government offices and residences from Google Maps as shown in Table 2 and Figure 5.

**Table 2** Distance of government offices and residences

| Distance (km) | A1 | A2 | ... | A44 | A45 |
|---|---|---|---|---|---|
| A1 | 0 | 0.11 | ... | 3.2 | 11.3 |
| A2 | 0.11 | 0 | ... | 3 | 11.1 |
| ... | | | ... | | |
| A44 | 3.2 | 3 | ... | 0 | 8.1 |
| A45 | 11.3 | 11.1 | ... | 8.1 | 0 |


**Figure 5** Distance between A1-A2 from Google Maps

4.2.5 The quantity of waste collection units is assigned based on the equivalence that 100 liters of trash is equal to one unit as shown in Table 3.

**Table 3** The quantity of waste collection units

| Code | Waste Collection Points | Quantity of waste collection units | | |
|---|---|---|---|---|
| | | 100 (liters) | 200 (liters) | Total (Unit) |
| A1 | CRMA Transportation Section Headquarters | 12X1 | 3X2 | 18 |
| A2 | CRMA General Support Division Headquarters | 8X1 | 0 | 8 |
| ... | ... | ... | ... | ... |
| A44 | CRMA Club | 0 | 6X1 | 6 |
| A45 | Landfills Prommanee Sub-district Organization | 0 | 0 | 0 |

4.2.6 Loading restrictions include the type of waste truck and loading capacity in liters and units as shown in Table 4 and Figure 6.

**Table 4** Loading restrictions of the waste truck

| Type | Loading Capacity (liters) | Loading Capacity (Unit) |
|---|---|---|
| Compacted Waste Truck | 30,000 | 300 |

**Figure 6** HINO Waste Truck Model MNKFG8JJ1XHX

**4.3 Application of a mathematical model for VRP**

This research considers the application of a mathematical model for the Vehicle Routing Problem or VRP [11]. The variables are defined as follows.

**Index**

i,j are the transport section, government offices and residences where i or j; i,j = 1,...,45.

k is a compacted waste truck where k = 1.

p is the start and end of any i or j point.

**Parameter**

$D_{ij}$ is the travel distance from point i to j.

$a_k$ is the load of a truck equal to 300 units.

$q_i$ is the amount of waste collection units in terms of any point i or j.

**Decision Variable**

$X_{ij}^{k}$ is 1 when vehicle k travels from location i to j, and 0 when it has not traveled.

$U_i^k$ is the decision variable for eliminating the route of incomplete laps or sub tours.

$Y_i^k$ is 1 when point i is traveled by vehicle k and 0 when it has not traveled.

**Objective Function**

$$Minimize = \sum_{k=1}^{K}\sum_{j=1}^{N}\sum_{i=1}^{N} D_{ij} X_{ij}^{k} \quad (1)$$

where equation (1) is the minimum distance traveled from point i to point j by vehicle k.

**Constraints Function**

$$\sum_{j=1}^{N} X_{1j}^{k} \geq 1 \quad (2)$$

where Equation (2) states that truck k = 1 will leave from transport section i = 1 and travel to at least one government office j.

$$\sum_{i=0}^{N} X_{ip}^{k} - \sum_{j=o}^{N} X_{pj}^{k} = 0 \quad (3)$$

Where Equation (3) states that government offices will travel in and out equally.

$$\sum_{k=1}^{K} Y_i^k = 1 \quad (4)$$

Where Equation (4) states that government offices will be traveled by truck equal to 1 vehicle.

$$\sum_{i=1}^{N} q_i Y_i^k \leq a_k \quad (5)$$

Where Equation (5) states that the truck will not carry more than its capacity.

$$Y_i^k \leq \sum_{j=0}^{N} X_{ji}^{k} \quad (6)$$

where Equation (6) states that point i can only be reached if vehicle k travels through point i from any path of point j.

$$\sum_{k=1}^{K}\sum_{i=0}^{N} X_{ij}^{k} \geq 1 \quad (7)$$

where Equation (7) states that point j will be traveled by truck at least once through the route from point i.

$$\forall X_{ij}^{k} \in \{0,1\} \quad (8)$$

where equation (8) is the conditional equation showing that all variables X can be either 0 or 1.

**Equation Prevents Sub-Tour**

$$[(U_i^k \geq U_j^k)+(q_i - a_k)+ \left(a_k \times \left(X_{ij}^k + X_{ij}^k\right)\right) - X_{ij}^k(q_i + q_j)] \quad (9)$$

$$U_i^k \leq a_k + (a_k - X_{0i}^k(a_k - q_i)) \quad (10)$$

$$U_i^k \leq q_i + \sum_{j=1}^{N} q_j X_{ji}^{k} \quad (11)$$

where equations (9) to (11) are substitutions of the variables to obtain possible solutions and prevent the occurrence of Sub-Tour.

**4.4 Application of the program for optimal solution**

4.4.1 Change the mathematical equations and constraint equations according to Section 4.3 into the form of a program for solving the best value problem.

4.4.2 Check the format of the program for the best value solution.

4.4.3 Apply the distance by designing the route and 45 Waste Collection Points must be traveled.

## 5. Result and Discussion

**5.1 Analysis of Waste Collection Route Results with VRP Mathematical Model Method.**

In problem solving with a VRP Mathematical Model Method for 45 Waste Collection Points. The program for optimal solution takes more than 24 hours to calculate. The researcher stopped calculating the program at 26 hours to determine the reason for the long computation of the program. The information obtained is as follows: the route was 53.68 kilometers with a calculated time of 26 hours. There are a total of 6 transport routes and 1,282 waste collection units as shown in Table 5.

According to the data from Table 5, the 2$^{nd}$ Route has two waste collection points and three waste collection units. In contrast, the 4$^{th}$ Route has 14 waste collection points and 290 waste collection units. These results exhibit significant differences. However, utilizing this approach on the actual route might result in unnecessary distance and increased transit time.

**Table 5** Route Order of VRP Mathematical Model

| Route No. | Route Order | Distance (km) | Load (Unit) |
|---|---|---|---|
| 1 | A1-A2,A2-A35,A35-A32, A32-A33,A33-A34,A34-A36,A36-A37,A37-A41, A41-A42,A42-A38 & A38-A1 | 10.01 | 300 |
| 2 | A1-A3 & A3-A1 | 0.9 | 3 |
| 3 | A1-A6,A6-A5,A5-A4, A4-A31,A31-A30,A30-A27, A27-A29,A29-A28,A28-A13, A13-A12,A12-A17& A17-A1 | 6.16 | 273 |
| 4 | A1-A8,A8-A9,A9-A10, A10-A14,A14-A15,A15-A26, A26-A25,A25-A24,A24-A45, A45-A44,A44-A20,A20-A21, A21-A19 & A19-A1 | 28.16 | 290 |
| 5 | A1-A11,A11-A7 & A7-A1 | 1.9 | 136 |
| 6 | A1-A16,A16-A18,A18-A22, A22-A23,A23-A40,A40-A39, A39-A43 & A43-A1 | 6.55 | 280 |
| Total | | 53.68 | 1,282 |

**5.2 The observations in the relevant research studies in Section 3.4**

After examining the index values and parameters of equations in J. Banthao [11] research , it is evident that the application of the VRP Mathematical Model is more suitable for a sample consisting of a smaller number of delivery points. This finding supports the theory that Optimization is an NP-Hard problem, necessitating significant time and yielding multiple solutions that can't be feasibly computed within a limited timeframe. To obtain a solution that is both close to optimal and acceptable within a shorter calculation time, Heuristic Methods are employed. These methods enable rapid computations. The VRP model offers valuable insights into the group of government buildings with the highest waste volume, which is crucial for the heuristic method as shown in Table 6.

**Table 6** The highest amount of waste point in CRMA

| Code | Waste Collection Points | Load (Unit) |
|---|---|---|
| A11 | Student Battalion 1–4 | 110 |
| A25 | Flat Kor.1–Kor.12 | 144 |
| A30-31 | Residence and PX of the CRMA Infantry Battalion | 120 |
| A41 | Residence C (Academic Division) | 144 |

Based on the information presented in Table 6, the four waste collection points with the highest amount of waste are Student Battalion 1–4, Flat Kor.1–Kor.12, Residence and PX of the CRMA Infantry Battalion and Residence C (Academic Division). These four waste collection points are marked with red stars, while other waste collection points are represented by blue circles as shown in Figure 7.

**Figure 7** The highest amount of waste in CRMA

**5.3 Analysis of Waste Collection Route Results with Heuristic Method.**

In the research conducted by P. Chunchaiphak [7], various heuristic methods were studied for path finding. The researcher specifically selected the Cluster-First Route-Second and Sweep Heuristic methods to identify routes with the shortest distance.

**5.3.1 Application of Cluster First Route Second+ VRP 2 Group and VRP 3 Group method.**

The Cluster-First Route Second method involves finding routes by grouping waste collection points based on vehicle load capacity. Then design transportation routes within each group before moving on to other groups as shown in Figure 8.

5.3.1.1 Determined from the highest amount of waste point in CRMA in Table 6

5.3.1.2 Divide routes within the group into 2 groups using 2 vehicles. Then design the route with the VRP mathematical model.

5.3.1.3 Divide routes within the group into 3 groups using 3 vehicles. Then design the route with the VRP mathematical model.

5.3.1.4 Check the results and the distances.

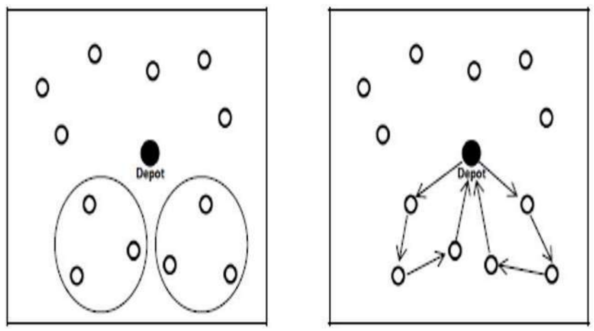


**Figure 8** The Cluster-First Route-Second Method

**5.3.2 Application of the Sweep Heuristic**

The Sweep Heuristic method involves dividing waste collection points into groups by sweeping them either clockwise or counterclockwise. The division takes into account the number of waste collection units until the capacity of the vehicle is not exceeded. The vehicle then returns to the starting point and completes all loops. Transportation routes are then designed within each group before moving on to other groups as shown in Figure 9.

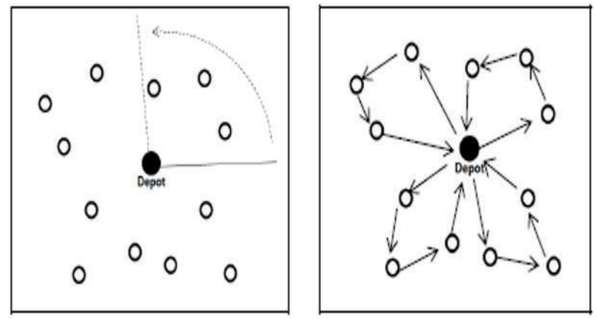


**Figure 9** The Sweep Heuristic Method

**5.4 Results of Designing Waste Collection Routes by Various methods**

There are four methods of designing routes to optimize distance, which include:

5.4.1 Design a route with the VRP Mathematical Model Method using one vehicle. The number of routes is six, with a total distance of 53.68 kilometers and the amount of waste collected in units is 1,282.

5.4.2 Design a route with the Cluster First Route Second+ VRP 2 Group Method using two vehicles. The number of routes is five, with a total distance of 75.66 kilometers and the amount of waste collected in units is 1,282.

5.4.3 Design a route with the Cluster First Route Second+ VRP 3 Group method using three vehicles. The number of routes is five, with a total distance of 94.06 kilometers and the amount of waste collected in units is 1,282.

5.4.4 Design a route with the Sweep Heuristic Method using two vehicles. The number of routes is five, with a total distance of 110.81 kilometers and the amount of waste collected in units is 1,282. The results are shown in Table 7 and Figure 10.

**Table 7** Routing Results in Various Methods

| Method | Vehicles (cars) | Path (routes) | Distance (km) | Load (Unit) |
|---|---|---|---|---|
| Present | 2 | 5 | 110.71 | 1,282 |
| VRP | 1 | 6 | 53.68 | 1,282 |
| Cluster 1st Route 2nd + VRP 2G | 2 | 5 | 75.66 | 1,282 |
| Cluster 1st Route 2nd + VRP 3G | 3 | 5 | 94.0 | 1,282 |
| Sweep Heuristic | 2 | 5 | 110.81 | 1,282 |

From the data in Table 7 and Figure 10, The VRP Mathematical Model Method gives the shortest distance but can't be used because the set of customers or 45 waste collection points in CRMA would provide multiple answers and take longer to calculate as the amount of variables increases. The distance and route information obtained from the calculation of 26 hours of the program is still not the optimal answer. The researcher has applied the Heuristic Method to help find the answer. The route applied to waste collection is a route design with Heuristic Method, Cluster First Route Second+ VRP 2 Group using 2 vehicles that provides an answer close to optimal so that route design can be practical and acceptable as shown in Figure 11.

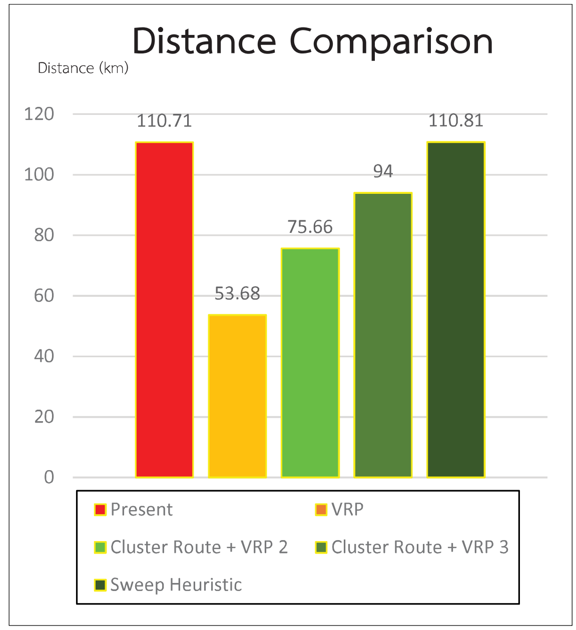


**Figure 10** Comparing Distances in Various Methods

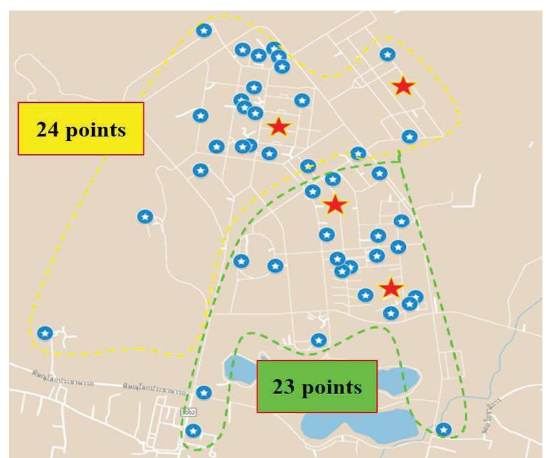


**Figure 11** The Cluster First Route Second + VRP 2 Group Method

Based on Figure 11, a comparison of the current transportation distance reveals that there are two vehicles, five routes, and a total distance of 110.71 kilometers. To optimize the route design, adjustments were made using the Cluster First Route Second + VRP 2 Group approach, while utilizing the same vehicle. The waste collection process was divided into two groups: the 1st truck was assigned to collect waste from 24 government offices, and the 2nd truck was assigned to collect waste from 23 residential groups.This division resulted in a reduction of 35.05 kilometers or 31.66 percent of the original distance. The results are presented in Figure 12.

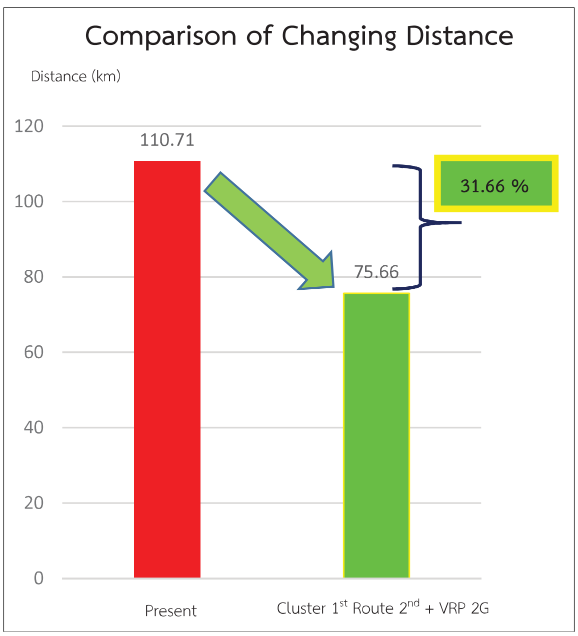


**Figure 12** Comparison of changing distances

### 5.5 Results of Cost Analysis

Cost considerations demonstrate that route design enables transport departments to reduce transportation costs. Currently, the fuel consumption rate of waste truck is 0.803 km/liter in one week and the diesel price of Dec 2022 [12] is 34.94 baht/liter. The comparison cost as shown in Table 8.

**Table 8** Comparison of the transportation cost

| Method | Distance (km) | Fuel Rate (km/liter) | Fuel Used (liter) | Cost (Baht) |
|---|---|---|---|---|
| Present | 110.71 | 0.803 | 137.87 | 4,817.19 |
| Cluster 1st Route 2nd + VRP 2G | 75.66 | 0.803 | 94.22 | 3,292.11 |

Based on the cost analysis, it was determined that the initial transportation cost amounted to 4,817.19 baht. However, after implementing the waste collection route design, the cost decreased to 3,292.11 baht or 1,525.09 baht per week.

## 6. Conclusion and Recommendation

### 6.1 Conclusion

From the study, the researcher made observations regarding the application of the VRP mathematical model for the optimization method. It was found that when the number of waste collection points or customer sets exceeds 30 points, the optimization program takes a significant amount of time to compute and fails to provide a solution within a day. Possible answers increase based on the waste collection point, so the optimization method is suitable for research where transport point variables are relatively low. Therefore, it can be calculated quickly with the optimal program such as the research of P. Kabcome and T. Mouktonglang [9] and J. Banthao [11]. In academic research, heuristic methods are commonly favored for designing and solving route problems, as they are not restricted by limitations on transportation points. The solutions generated by these methods are often in close proximity to the optimal and widely accepted answers, as evidenced by the works of P. Chunchaiphak [7], P. Phanphiphat and P. Khemavuk [8] and N. Rungrodchatchaval [10].

Based on the data obtained from the research and the facts presented in the CRMA case study, the researcher opted to employ the heuristic method known as the Cluster-First Route-Second Method. This approach involved segmenting the route prior to designing the route using the VRP mathematical model. The objective was to reduce the number of variables associated with waste collection points, which originally totaled 45 waste collection points. The transportation was divided into two groups, comprising 24 government offices and 23 residential waste collection points, and utilized two waste collection trucks. Following the segmentation of the route, wherein the number of waste collection points didn't exceed 30, the transportation problem was transformed into the VRP mathematical model. The results obtained from the optimized program showcased reduced computation time compared to the previous approach. Additionally, the route model derived from this method proved effective in enhancing waste collection truck operations and minimizing unnecessary mileage.

Summarize the results of the study by applying the VRP mathematical model together with the heuristic methods, the Cluster First Route Second+ VRP 2 Group yields distance results that are consistent with the research objectives of the study and provide a suitable route model for this case study. The route model can reduce the transportation distance from 110.71 kilometers to 75.66 kilometers and reduce the transportation cost by 1,525.09 baht per week or 31.66 percent of the original transportation cost.

**6.2 Recommendation**

6.2.1 The application of the VRP mathematical model for the optimization method and heuristic methods should consider the factors of each case study because there are different limitations such as the number of transportation points, quantity of demand, number of vehicles and load capacity and etc.

6.2.2 This study solves the basic waste collection problem to help make waste collection more convenient and save resources. Further research is required to investigate variables such as travel time, more distribution points or multiple Depots and transit points with uncertainty.

6.2.3 The researcher utilized Google Maps to compute the travel distance, although there is a possibility of the route deviating from the actual transportation conditions. The route application should be adjusted based on the travel itinerary.

## 7. Acknowledgements

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